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A study of the long term variability of RX J1856.5–3754 with XMM-Newton

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Abstract. We report on a detailed spectral analysis of all the available XMM-Newton data of RX J1856.5–3754, the brightest and most extensively observed nearby, thermally emitting neutron star. Very small variations ($\sim 1\text{--}2\%$) in the single-blackbody temperature are detected, but are probably due to an instrumental effect, since they correlate with the position of the source on the detector. Restricting the analysis to a homogeneous subset of observations, with the source at the same detector position, we place strong limits on possible spectral or flux variations from March 2005 to present-day. A slightly higher temperature ($kT \sim 61.5$ eV, compared to the average value $kT \sim 61$ eV) was instead measured in April 2002. If this difference is not of instrumental origin, it implies a rate of variation of about 0.15 eV yr^{-1} between April 2002 and March 2005. The high-statistics spectrum from the selected observations is well fit by the sum of two blackbody models, which extrapolate to an optical flux level in agreement with the observed value.

1. Introduction

The X-ray Dim Isolated Neutron Stars (XDINSs, see Turolla (2009) for a review) are a small group of nearby, $d \lesssim 300$ pc, thermally-emitting neutron stars, characterized by temperatures $kT^\infty \sim 50\text{--}100$ eV, luminosities $L_X \sim 10^{31}\text{--}10^{32} \text{ erg s}^{-1}$, and spin periods in the 3–12 s range. They are radio-quiet and have very faint optical/UV counterparts, $m_V \sim 26\text{--}27$. Their spin-down rates ($\sim 10^{-14}\text{--}10^{-13} \text{ s s}^{-1}$) imply magnetic fields $B \sim 10^{13}\text{--}10^{14}$ G, in good agreement with those inferred from the broad spectral features observed in some of these sources.

Only one of the XDINSs, RX J0720.4–3125, showed significant long term spectral and flux variations (de Vries et al. 2004; Hohle et al. 2012), for which several interpretations were proposed, including precession of the neutron star and changes induced by a glitch (Haberl et al. 2006; van Kerkwijk et al. 2007). No evidence of variability has been reported in the other six members of this class, but most of them have not been observed very frequently and have lower fluxes than RX J0720.4–3125, therefore the derived limits are not very constraining.

On the other hand, RX J1856.5–3754 is the brightest XDINS and it has been routinely observed, almost twice per year since 2002 for calibration purposes, by the XMM-Newton X-ray satellite. The resulting large amount of data allows us to investigate its spectral evolution on time scales from months to ~ 10 years, but a reliable interpretation of these data requires to carefully consider the stability of the detectors and any calibration issue that might affect the results.

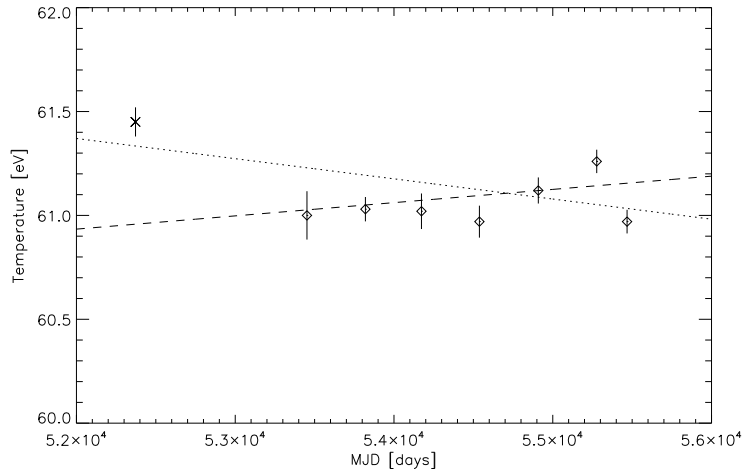


Figure 1. Long term evolution of the BB temperature from a set of homogeneous observations with the source at the same position on the EPIC pn detector. The dotted line is a linear fit to all the points. The dashed line represents a linear fit excluding the first point (April 2002).

2. Results

We studied the spectral evolution of RX J1856.5–3754 using all the available data obtained with the pn camera of the EPIC instrument on board XMM-Newton. These consist of 18 observations carried out between April 2002 and April 2012, for a total exposure time of more than 700 ks (after screening to remove periods of high background). Complex physical models have been used in the past to study the X-ray emission from RX J1856.5–3754 (see, e.g., Turolla et al. (2004); Ho (2007)), but, considering the lack of prominent spectral features¹, and the fact that we are mostly interested in the *relative* spectral variations, we restricted our analysis to fits with one or two absorbed blackbody (BB) models. All the fits were performed in the 0.15–1.2 keV energy range.

The fits with a single BB resulted in temperatures within $\sim 2\%$ of the average value $kT \sim 61.5$ eV. Although the very small statistical errors on the derived temperatures would imply significant variability, a closer investigation indicated that the apparent variations are most likely the results of instrumental effects (see Sartore et al.

¹in this respect RX J1856.5–3754 is unique among the XDINSs

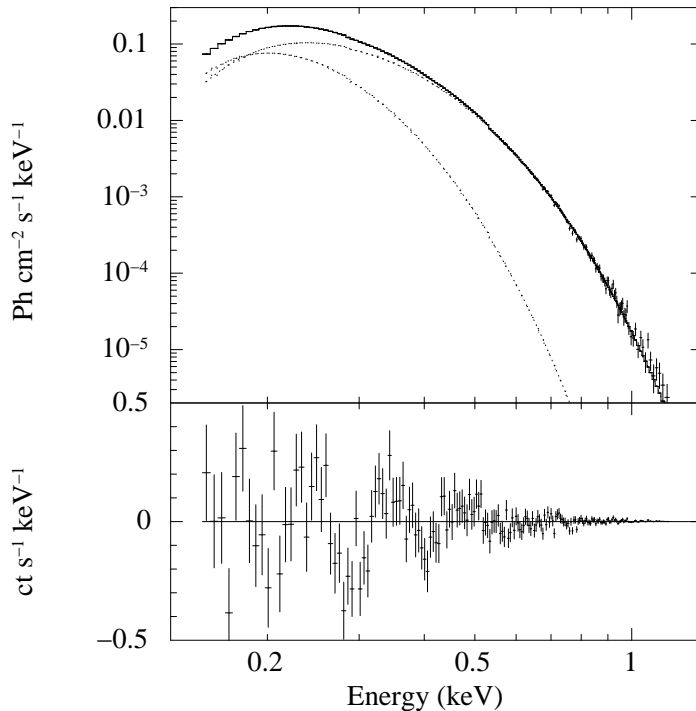


Figure 2. Spectrum of RX J1856.5–3754 extracted from a homogenous set of observations yielding a total exposure time of ~ 254 ks. The upper panel shows the best fit with two blackbodies. The features in the residuals (lower panel) have a width smaller than the pn energy resolution and are most likely due to non perfect instrumental calibrations.

(2012) for details). Due to the varying satellite observing constraints, the source was observed at slightly different positions of the EPIC pn detector. We found that the derived temperature correlates with the source position in instrumental coordinates, in particular with the CCD column. This indicates that the effect is probably caused by a non-corrected spatial dependence of the channel-to-energy conversion. Note that this is a very small effect, which is relevant in this particular case of a high-statistics spectrum of a very soft source, and it does not affect most EPIC/XMM-Newton observations.

To minimize this instrumental effect, we restricted all the further analysis to a subset of eight observations in which RX J1856.5–3754 was located at approximately the same detector coordinates. In this way we could set strong constraints on the relative variations in spectral shape and flux, but it must be remembered that a systematic uncertainty of ~ 1 -2% on the absolute values cannot be eliminated.

The single BB model temperature is compatible with a constant during the last ~ 5 years. A linear fit gives a rate of temperature variation of $\sim 0.023 \pm 0.015$ eV yr $^{-1}$, consistent with a constant at the 2σ level (see Fig.1). A higher temperature was measured in April 2002. If not caused by subtle alterations of the instrument response, this difference would imply that also RX J1856.5–3754 undergoes spectral changes, albeit much smaller than that observed in RX J0720.4–3125, which underwent substantial and con-

tinuous changes in its spectral properties during the years. The temperature variation of RX J1856.5–3754, ~ 0.5 eV in three years,² corresponds to a rate of ~ -0.15 eV yr⁻¹.

The high-statistics spectrum ($\sim 2 \times 10^6$ counts) obtained by summing the data of the homogenous observations is shown in Fig. 2, with the two BB best fit model (a single BB gives a significantly worse fit). The hard BB has a temperature of $kT_h^\infty = 62.4^{+0.6}_{-0.4}$ eV with emission radius of $R_h^\infty = 4.7^{+0.2}_{-0.3}$ ($d/120$ pc) km, while the soft BB has $kT_s^\infty = 38.9^{+4.9}_{-2.9}$ eV and $R_s^\infty = 11.8^{+5.0}_{-0.4}$ ($d/120$ pc) km. The column density is $N_H = (12.9 \pm 2.2) \times 10^{19}$ cm⁻². We found no convincing evidence for broad or narrow absorption features (see Sartore et al. (2012) for details).

The contribution of the soft BB at optical wavelengths is four times larger than that of the hard BB. This implies an overall increase of a factor ~ 5 with respect to the optical flux expected from the Rayleigh-Jeans tail of the hard BB alone. The resulting value is consistent, within the uncertainties, with the observed optical/UV flux (Kaplan et al. 2011).

3. Conclusions

We have carried out a detailed analysis to investigate the long term spectral variability of the brightest XDINS, reaching the limit set by the current uncertainties in the instrumental calibration, and without finding evidence for relative variations larger than a few percent during the last decade. We stress that the absolute values of the spectral parameters derived with XMM-Newton for RX J1856.5–3754 (and also for other very soft X-ray sources) must be taken with caution since they can be affected by systematic errors at the level of few percent.

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²or less, considering the lack of coverage between April 2002 and March 2005